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DYNAMIC TESTS OF V/STOL TRANSPORT MODELS

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INTRODUCTION

This paper presents a summary of results obtained in dynamic tests of free-flight models of various configurations suitable for V/STOL transport aircraft at the NASA Langley Research Center. The configurations covered will be the tilt-wing propeller-driven type as represented by the XC-142A tri-service transport, the fan-in-wing type as represented by the XV-5A research airplane, and the jet-lift type as represented by the Dornier DO-31 transport. The test techniques themselves are not described in this paper since they have been described in detail previously in references 1 and 2.

TILT-WING CONFIGURATION

Free-flight tests have been made with a number of tilt-wing V/STOL configurations, starting in 1955. The results of these investigations are reported in references 3 to 11. Recently tests have been made with the XC-142A configuration, but the results have not yet been reported. All of these tests have shown certain stability and control characteristics which are common to all of the configurations and are therefore considered characteristic of the tilt-wing configuration in general. All of these characteristics were evident to a certain degree in the XC-142A which is the most up-to-date configuration covered in dynamic model tests; so the results obtained with this configuration will be used for the purposes of illustration herein. A photograph of this model is shown in figure 1. The model has a double slotted flap that is programed to deflect down when the wing is at intermediate tilt angles between 0° and 90°. Control for hovering flight is provided by the tail rotor for pitch control, ailerons built into the trailing edge of the flap for yaw control, and differential pitch of the right and left propellers for roll control.

Hovering

Out of ground effect.- For hovering flight out of ground effect, the basic stick-fixed motions of the model were characterized by unstable pitching and rolling oscillations as indicated by the time histories of figure 2. These oscillations are quite unstable in terms of the classical measure of cycles to double amplitude, but they can be controlled quite easily by the pilot because of their relatively long period - 10 and 18 seconds, full scale in pitch and roll, respectively. The full-scale VZ-2 tilt-wing research airplane had the same type of unstable oscillations but the pilot found them easy to control. In fact, he had flown the airplane many times before he realized that there were unstable oscillations. He was aware of the fact that the airplane tended to diverge, but he did not let the aircraft diverge long enough for the periodic nature of the motion to become evident. Only later during specific attempts to determine the characteristics of the uncontrolled stick-fixed motions was the periodic character of the motion observed in the full-scale flight tests. The unstable oscillations had been observed previously, however, in the free-flight tests of a 1/4-scale model of the VZ-2 reported in reference 6.

The total control power in pitch and roll required to deal with these unstable oscillations and otherwise provide satisfactory controllability in hovering has been found on the XC-142A model, and on all models flown previously, to be in agreement with the control power requirements specified in various appropriate specifications such as references 12 to 14 for helicopters and V/STOL aircraft. The fact that the pilot of a small-scale remotely controlled model would want the same (scaled-down) total control power as the pilot in a full-scale aircraft seems almost fortuitous. The tasks required of the pilot in pitch and roll are about the same as those confronting the pilot of the full-scale airplane, however. They are: hovering smoothly and precisely over a spot on the ground, rapid maneuvering from one position to another, and recovering quickly from inadvertent disturbances such as gust disturbances and from the unstable oscillations if they are inadvertently allowed to buildup. These tasks require a proper balance between the small control moments required for steady flight in still air and the large control

moments required for maneuvering and for coping quickly with disturbances. Because of this similarity of tasks and considerations, therefore, perhaps it is not so surprising that the control power requirements of the model scale properly to represent those of the full-scale airplane.

For the yawing mode of motion, however, the flying model tests do not agree as well with the requirements of the full-scale airplane. This difference is probably the result of the model flight test technique. Neither the model nor the full-scale aircraft have any stability (or instability) in yaw. They do not tend to either diverge from a given heading or to return to it is disturbed. Consequently, the task of maintaining a heading requires little control for hovering out of ground effect. This is the only task assigned the yaw control pilot for hovering tests of the free-flight model where if the model yaws through large angles the remotely located pilots lose their orientation. For the full-scale aircraft, however, the pilots wish to be able to turn the aircraft rapidly and this maneuver requires a higher level of control power than is required in the model tests.

In ground effect.- There is a pronounced favorable ground effect on lift for tilt-wing aircraft which results primarily from the fact that positive pressures are induced on the bottom of the fuselage because the recirculating propeller slipstream flows upward along the plane of symmetry when the aircraft is hovering near the ground. This type of flow and its effects have been discussed in many previous papers such as references 15 to 17. For large flat-bottomed fuselages, such as that of the XC-142A, this ground effect can be very large as shown by the force test data of figure 3. There is also a smaller contribution to ground effect which results from the fact that the propellers themselves are influenced by their proximity to the ground. This is the well-known effect of ground proximity experienced by helicopters. It is a relatively small part of the whole picture in the tilt-wing aircraft, however, because the propellers are not very close to the ground in terms of their own diameters. This contribution to the total ground effect is shown in reference 16.

The ground effect on lift gives a very pronounced height stability for hovering very close to the ground and makes the maintenance of a constant height a very simple task for the pilot since he hardly has to manipulate the throttle at all.

Another manifestation of this ground effect is its effect on stability in pitch and roll. Ground proximity has a pronounced static stabilizing effect in pitch and a lesser one in roll as shown by the force test data of figure 4. The stabilizing effect in pitch evidently results from the lift on the bottom of the fuselage resulting from the ground proximity which would be expected to be greater on the end of the fuselage closest to the ground and thereby produce the static stability in pitch shown in figure 4. The stabilizing effect in roll evidently results from the fact that the proximity to the ground causes the thrust of the propellers closest to the ground to be the greatest and thereby causes the static stability in roll.

The effects of the static stability in pitch on the dynamic stability of the model show up very graphically from figure 5. This figure shows that the uncontrolled stick-fixed pitching motions of the model which were very unstable for hovering out of ground effect were about neutrally stable for the case of hovering near the ground. The time history of figure 5 shows that the oscillation did not diverge when the model was very near the ground and diverged slowly when the model rose slightly higher above the ground. This ground effect on the pitching motions, which is quite dependent on the shape of the bottom of the fuselage was found to occur to an even greater degree in tests of a model of the X-18 airplane reported in reference 5.

The results of the static stability in roll on dynamic stability was not nearly as apparent as the effect in pitch, but the pilots observed that the XC-142A model was somewhat easier to control in roll when hovering in ground effect than when hovering well above the ground.

The yawing motions of the XC-142A model were much more erratic and difficult to control when hovering near the ground than when hovering out of ground effect. In ground effect the model appeared to be subjected to more frequent and larger yawing disturbances. This type of behavior has been noted previously with other dynamic models and also with

the full-scale VZ-2 airplane in flight tests as indicated by references 18 and 19. The problem had been studied in some detail in reference 17, and it seemed that the erratic disturbances resulted from the unsteady nature of the upward flow of the slipstream along the aircraft center line. This unsteady flow switches from side to side and causes the inflow to the propellers to vary so that the propellers cause large random moments. Also, it seems likely that this unsteady flow at the tail of the airplane might be a source of erratic yawing disturbances. In any event, the model is subjected to erratic yawing disturbances when hovering near the ground.

The proximity of the ground also causes the yaw control provided by the ailerons to become weaker as the model nears the ground so that the control available to combat yawing disturbances is lessened at the time the yawing disturbances are increased. This reduction in yaw control is shown by the force test data of figure 6. The reason for this reduction in yaw control effectiveness is explained in reference 20 which indicates that it results from the fact that the slipstream velocity in which the ailerons are operating is reduced in the region near the ground.

Transition

Level flight.- The longitudinal stability of the XC-142A model in the transition range of flight is illustrated in figure 7. These data show that the unstable stick-fixed oscillation which had been noted in hovering became less unstable as the wing incidence was reduced and that the model was stable at an incidence of 10°. The data also show that the period became very long in the transition range so that it is doubtful whether the pilot of the model or a full-scale airplane would ever be aware of the fact that there was an oscillation unless he specifically looked for it.

The directional behavior of the XC-142A model in the transition range was characterized by rather annoying small-amplitude yawing motions of a random character. This type of behavior is characteristic of models which have low or neutral static directional stability for small angles of sideslip but have adequate directional stability at higher sideslip angles. Force tests of the model showed that it did have such static directional stability characteristics and that the use of a larger vertical tail would

increase the directional stability over the entire sideslip range. Consequently a larger vertical tail was tried in flight tests and was found to make the dynamic directional behavior of the model satisfactory. Since it did not seem that the vertical tail of the full-scale airplane would be enlarged, however, the tail extension was removed and the remainder of the tests were made with the original tail.

The lateral stability of the model was much better in transition than in hovering flight. In fact, the unstable rolling oscillations encountered in hovering flight, as indicated in figure 2, had disappeared by the time the wing incidence was reduced to 65°. At all lower angles of incidence the rolling oscillations of the model, which could probably be called Dutch roll oscillations because of the forward speed and the probable coupling with the yawing motions, were stable. The pilot could disturb the model in roll and the ensuing oscillation would quickly damp out. No time histories of this motion were obtained, however, because there were no cameras located in a position suitable to record it. With the evident high degree of lateral stability the pilot found the model to be quite easy to control laterally.

Descent conditions.- Descending flight conditions are simulated in free-flight tests in the Langley full-scale tunnel by use of the technique indicated by figure 8. This figure shows the balance of forces involved in actual descent at the left and in the simulated descent at the right. For a descent condition, the aircraft must have a net aerodynamic drag, and the lift, drag, and weight forces are in balance with the drag being balanced by the forward component of the weight acting along the flight path. In order to simulate the descent condition in the horizontal airstream of the tunnel, the model is flown with the same lift and drag (same angle of attack and power setting) and a thrust force is added by means of a small compressed-air jet at the rear of the model to balance the drag of the model. In this way the aerodynamic effects of descent conditions, which are very important for the tilt-wing V/STOL configuration, can be simulated in horizontal flight in the tunnel.

The descent tests were conducted to study the effect of wing stalling which has been found in previous full-scale and model flight tests such as those of references 11, 18,

and 19 to cause the dynamic behavior of the aircraft to become so poor as to limit the rate of descent that the pilot is willing to use in the airplane. The stalling results from the reduced slipstream velocity over the wing due to the reduced power used in the descent conditions. This effect is discussed in detail in reference 21.

Figure 9 presents the results of the descent tests of the XC-142A model in the form of pilot ratings of the behavior of the model for a range of descent angle and wing-incidence conditions. The pilot rating system used in the model tests is similar to the Cooper pilot rating system used in full-scale flight work and is shown in table I where it is compared with the Cooper rating system. The use of this system does not imply that the model technique can predict, quantitatively with fine graduation, the full-scale characteristics. Rather, the model ratings are alined with the Cooper rating system by use of the $3\frac{1}{2}$ and $6\frac{1}{2}$ boundaries between satisfactory, unsatisfactory, and unacceptable characteristics. The intent of the model ratings is to consider, through past experience, what type of behavior of the model would represent the behavior required of an airplane to meet the conditions listed under the Cooper system as to whether the mission could be accomplished, the aircraft landed, whether acceptable for normal operating conditions or only for emergency conditions, and to present these ratings with a system that would be familiar to the most people.

The results of the descent tests presented in figure 9 show pilot ratings obtained at wing incidences of 20°, 30°, 40°, and 50° for descent angles of 0°, 5°, 7°, 10°, 13°, and 15°. At each point, two ratings were obtained - (1) a rating of the behavior of the model when reasonably smooth and steady flight was maintained, and (2) a rating for disturbed flight after the model had intentionally been given a large disturbance or had been allowed to build up its own large-amplitude disturbed motion. At small descent angles the model was very stable and had to be intentionally disturbed with controls, after which the disturbed motion damped quickly, so for these conditions there was no difference between the two ratings. At higher descent angles, around 10°, it was difficult at some wing incidences to establish steady flight conditions and two ratings are

given. And, at the greatest descent angles, steady flight was not possible so that only a disturbed-flight rating was given. The ratings shown in figure 9 are overall ratings obtained from individual ratings on lateral, directional, longitudinal, and power characteristics.

For convenience in discussing the model pilots' interpretation of the results, the ratings are summarized in figure 10 in the form of boundaries on a plot of flight-path angle against wing-incidence angle. Figure 10 shows a 6° descent capability, above the dotted area, where no difference from level flight was detected even when the model was intentionally disturbed. As the descent angle was increased in the dotted area the model required more and more pilot attention to the controls and flow disturbances could be noticed occasionally from tufts. It was felt that, although the model characteristics were not unacceptable in the dotted area, the flow disturbances noticed could mean that buffeting would be a factor in this region of flight for the full-scale aircraft. At the higher descent angles in the dotted area the model did not settle down quickly after a disturbance and in the cross-hatched area, the model experienced abrupt wing dropping, abrupt losses in height, and the generally sloppy, wallowing motions normally associated with extensive wing stall. It was felt that the characteristics were completely unacceptable in this region. Figures 11 and 12 are graphic examples of how the results of stalling show up in the model flights. Time histories of the model motions in controlled flight for which the pilot was trying to fly smoothly are shown in figure 11 for the level-flight and 13° descent flight conditions for a wing incidence of 30°. In each case the angle of roll and angle of yaw is plotted against model time. In level flight the model was very easy to fly and required only occasional corrective control. The erratic wallowing motions at 13° descent angle, however, were extremely difficult to control; and, in fact, control of the model was lost at times during some tests for this condition. Figure 12 shows time histories of the model motions at 7° and 10° descent angle after the model had been intentionally disturbed from a smooth flying condition. At 7° descent angle, two rapid control pulses were used by the pilot to set up the motion and he was able to restore the model to smooth flight quickly since the basic lateral motions were

well damped. At 10° descent angle, the model motions were already erratic at the start of the test and only one control pulse was needed to cause the wild, wallowing motions shown in the figure which the pilot was barely able to control at all.

Other characteristics of the model motions in descent flight were observed that cannot be expressed by simple ratings. For example, at times, in the tests reported above, the model would drop in height abruptly without any appreciable effect on the lateral-directional characteristics being noted. This abrupt loss in height was a new type of motion not previously experienced with the VZ-2. From watching the tufts on the wing, it was evident that the abrupt dropping was caused by an abrupt symmetrical stall over a large part of both the left and right wing panels. Another characteristic noticed was that at high descent angles, somewhat different model motions were obtained at low wing incidence than at high wing angles. For example, at 20° wing incidence, steady flight could be achieved quite easily and with no apparent stalling to about 10° descent angle. However, if a disturbance occurred at this point, the resulting abrupt wing dropping and generally sloppy, wallowing motions were very difficult to control and a rating of seven resulted. At 50° wing incidence, however, the tufts showed disturbed flow on the wing long before the model motions were appreciably affected. This effect can probably be explained by the fact that at the high incidence of the thrustline and high flap deflection at 50° wing incidence, most of the weight was supported by power rather than by wing lift so that wing stall affected only a very small part of the total lift.

Normally, small-scale tests would not be too suitable for representing the stall or other flight conditions involving separated flows because of the discrepancy in Reynolds number. Experience has shown, however, that the stall of a small-scale model usually occurs at a lower angle of attack than that for the corresponding airplane, and also, that when the stall does occur, the resulting motions are generally quite similar. In the case of the descent tests, therefore, it would be expected that the effect of low Reynolds number would tend to give conservative results and, that in any event, the free-flight model technique gives a good qualitative indication of the type of resultant motion expected as the rate of descent is increased.

<u>Control power required</u>.- The control power required in pitch in the transition range was not evaluated in detail since it has been found in the past that the major requirements for pitch control are those imposed by the need to trim out the pitching-moment variations that develop during the transition range and to do this for the entire center-of-gravity range. These factors can generally be evaluated better from conventional wind-tunnel force tests than from the model flight tests. The maneuvering requirements superimposed on the trim requirements have generally been found to be a small part of the total pitching moment required.

The roll control required in transition for the XC-142A model was evaluated very carefully because this is an area of much current interest. It is felt that these model results would be directly applicable to the full-scale airplane because the task performed by the pilot of the model is much the same as that of the pilot of the full-scale airplane and because the model results on roll control have been found to agree with full-scale flight-test results in hovering.

The results of the roll control evaluation are shown in figure 13. These data (scaled up to full scale) show that the control power found to be required in the model tests agreed with the helicopter requirements at the low-speed end of the transition range, as pointed out previously, and with the normal airplane requirement for a value of $pb/2V$ of 0.07 at the high-speed end of the transition range. At intermediate speeds, the roll control required was found to be somewhat less than was required in hovering. These control power requirements were actually determined by the control power required in the descent conditions where the lateral behavior of the model was poor because of wing stalling as previously explained. The tasks performed by the pilot in evaluating the control power required were (1) flying the model smoothly and steadily, (2) maneuvering the model from side to side precisely, and (3) recovering from the lateral oscillations after they had been allowed to build up. The turbulence of the tunnel airstream is believed to offer a fairly severe test since it is characterized by fairly large-amplitude long-period fluctuations in airspeed and angle. The actual magnitude of the airstream fluctuations involved in this type of turbulence has not been measured, but

observation of the motions of conventional airplane models flying in the tunnel indicates conditions corresponding to fairly rough air.

The yaw control power required in the tests of the model is shown in figure 14. These results show that the model required less control power than is indicated by the helicopter requirements for hovering flight and that the control power required in the transition range was somewhat less than that required for hovering. It is felt that the piloting task involved in the flying model tests was less demanding than that required of the full-scale airplane; and, consequently, it is felt that the control power indicated as being adequate in the model tests might not be adequate for the full-scale airplane. As pointed out in reference 22, the pilot must have very powerful yaw control for instrument approaches at low speeds in the transition range, and he must also have adequate control to correct heading quickly just before touchdown on crosswind landings. These are probably the most demanding conditions for yaw control, and neither of these conditions was simulated in the flying model tests.

FAN-IN-WING CONFIGURATION

Flight tests have been made with only one fan-in-wing configuration to date, and these tests have not been completed; so that the discussion for this type of V/STOL aircraft is less detailed than that for the tilt-wing configuration, and it is less certain whether the results obtained are characteristic of a class of aircraft or peculiar to the one design tested. The configuration tested is that of the XV-5A airplane, and the flying model is shown in figures 15(a) and 15(b). The airplane derives its lift for hovering flight from two large tip-turbine driven fans in the wings and a smaller fan in the nose. The transition is accomplished by deflecting the exhaust of the wing fans rearward by means of louvers beneath the fans. For conventional forward flight, the turbojet engine exhaust is diverted from the fan turbines to conventional tailpipes beneath the tail and the fans are covered over to form wing and fuselage nose contours.

The control system used on the model was not the same as that used on the full-scale airplane. On the full-scale airplane pitch control for hovering is provided by the

scoops under the nose fan and height control, roll control, yaw control, and the forward force required for transition are all provided by louvers under the wing fans. For the model, pitch trim was provided by the scoops under the nose fan and the forward force required for transition was provided by the wing-fan louvers, but all other control (roll, yaw, and the additional pitch required for maneuvering) was provided by jet reaction controls at the wing tips and rear of the fuselage. The object in using this jet reaction type of control was to permit a determination of the basic stability and controllability of the fan-in-wing type of V/STOL airplane without the possibly confusing effect of the particular novel type of control system of the XV-5A which was quite difficult to actuate mechanically on the small-scale model.

Hovering

Out of ground effect.- The model had unstable stick-fixed oscillations in both pitch and roll as shown by the time histories of figure 16. These data show that the period of the two oscillations and the degree of instability were fairly similar. The pilots found, however, that the model was quite easy to control in pitch, but was very difficult to control in roll - even with control power about each of the two axes set at the optimum value for that axis. It seemed that the reason for this difference was that the model was much more sensitive to disturbances in roll than in pitch. This extreme sensitivity seemed to result from the fact that the model had a very high dihedral effect (rolling moment due to sidewise velocity) and relatively low moment of inertia in roll. The disturbances in this case were random fluctuations in the recirculating fan slipstream in the large enclosure where the tests were made. No measurements have been made with this, or any other model, to determine the degree of gustiness of the air in the test area except by the qualitative observations of persons standing near the model. From such observations, however, it seems that the velocity changes involved in the disturbances are probably small compared with those that would be encountered outdoors on a gusty day, but they might have been more frequent than outdoor gust disturbances.

As part of the investigation of the rolling problem of this model, the moment of inertia in roll was increased 30 percent in an attempt to reduce the response of the

model to disturbances. This change gave some improvement in the ease with which the pilot could control the model in roll. There might be some question as to whether the improvement in controllability of the model resulting from the increase in moment of inertia resulted from a decreased sensitivity to disturbances or from an increase in the period of the rolling oscillation. The period of the oscillation for the basic condition was at least 4 seconds (model scale), however, which is not critically short, so the increase in period would not seem to be the important factor.

As another part of the investigation of the problem in roll, chordwise fences were installed on the upper surface of the wing just outboard of each wing fan. These fences, which did not appreciably affect the static thrust, were $1\frac{1}{2}$ inches high and extended over the middle 60 percent of the chord. The model pilot felt that the installation of these fences resulted in the model being much easier to control in roll although the time histories of figure 17 show there was very little difference in the stability of the developed stick-fixed motions with or without the fences. In fact, the period of the oscillation was reduced somewhat with the fences in place. Apparently, then, the improved flight behavior resulted from a reduction in the model's sensitivity to a disturbance, particularly the rolling moment due to sidewise velocity. The pilot also felt that a contributing factor might have been that he required a high control sensitivity to contend with the erratic, large-amplitude motions of the basic model and this resulted in some pilot-induced disturbances. The installation of the fences allowed a reduction in the control sensitivity to a level where pilot overcontrolling was not a factor in the model's flight behavior.

One further investigation was made of the problem in roll. The basic model was equipped with artificial stabilization equipment to provide additional damping in roll (rolling moment due to rolling velocity). It was found that by the addition of sufficient artificial damping in roll the rolling oscillation could be made completely stable and the response to disturbances could be reduced to the point that the rolling motions of the model became very easy to control.

No corresponding study of the pitching motions was made since it was felt that the model was sufficiently easy to control in its basic condition without stability augmentation.

The total control power available on the model to deal with these unstable motions in both pitch and roll in hovering flight were those specified as being available on the full-scale airplane which were also roughly the same as the control power specified in the requirements of reference 12. The model control powers were found to be completely adequate although a detailed investigation of the minimum requirements was not made.

In ground effect.- Very little work has been done on the ground effects on the XV-5A model because of the difficulty of controlling the rolling motions which endangered the model. A few take-off tests have been made, however. In these tests no appreciable suck-down or lift-augmentation effect due to ground proximity was noticed. A ground effect on pitching moment was very evident, however. When the model was trimmed for hovering flight out of ground effect, a very pronounced nose-up pitching moment was evident when it was in ground effect. This pitching moment was evident as a marked tendency for the model to pitch up and move backward as it broke ground on take-off. This nose-up motion could be prevented by the pilot, however, by the use of nose-down pitch control just as the model left the ground.

The nose-up pitching moment in ground effect is believed to result from the use of the nose fan in the XV-5A configuration and might not be typical of fan-in-wing configurations in general. It seems that the use of the nose fan in conjunction with the wing fans would cause a strong positive pressure on the underside of the fuselage forward of the center of gravity because of the upward flow of the fan slipstreams at points between the fans.

Transition

The only flights in the transition range made to date with the XV-5A model have been in the level-flight condition, and no descent conditions have been tested.

The longitudinal stability of the model in the transition range of flight is illustrated in figure 18. This figure shows that the stick-fixed pitching oscillation which had been noted in hovering became less unstable as the airspeed was increased and that the model appeared to be stable at the highest speed reached in the tests. This speed is approximately the speed at which the conversion to conventional wing-borne forward flight could be made. The conversion was not actually made in the model tests, however, because of the difficulty of making the conversion without changes in airspeed and height which would be too abrupt to be accommodated in the limited confines and with the slow speed control of the tunnel.

The rolling motions of the model, which had been found to be so troublesome in hovering flight, became progressively easier to control as the airspeed was increased in the transition range. Most of the flights were made with the roll stability augmentation system operating and the improvement was evidenced mainly in the need for a lesser degree of artificial damping in roll as the speed increased. At the speed at which the conversion to normal forward flight could be accomplished, however, the rolling motions had become essentially stable. It was not possible to tell whether they were actually slightly stable or slightly unstable since the model could not be allowed to fly uncontrolled for a sufficiently long period of time before it drifted sideways out of the test section of the tunnel.

There are several interrelated problems of static stability and trim that, in combination, can become critical on this particular configuration because it is operated close to the border line in several respects - and there is a way to relieve most of these problems. The primary problems are (1) that the model in its normal configuration was just barely able to propel itself by deflecting the fan louvers to the speed at which it could make the conversion to wing-borne flight, and (2) that it developed such large nose-up pitching moments in transition that the pitch control was barely able to trim the aircraft in the most critical region. The high drag that makes the propulsion critical is caused mainly by the momentum drag of the three fans which effectively take the static free stream air and accelerate it to the forward speed of the airplane so that it can

flow axially through the horizontal fans. The nose-up pitching moment results from the differential lift on the forward and rearward lips of the fans, which results from forward flight as explained in reference 23, and by a suction effect on the part of the wing behind the fan exhaust stream, which is caused by the interference of the fan exhaust on the free-stream flow as explained in reference 22.

At the higher speeds in the transition range where the drag problem is most critical, the nose fan is adding to these problems and creating new ones of its own and is not performing any useful function. In these conditions the nose fan causes added momentum drag and it produces increments of static longitudinal and directional instability because of its momentum drag. In this speed range the nose fan was not actually needed for longitudinal trim and control since the horizontal tail had sufficient effectiveness; and it was found to be advantageous to stop the nose fan and thereby eliminate the problems.

The nose-up pitching-moment problem was most critical at fairly low speeds in the transition where the horizontal tail did not have any appreciable effectiveness. The nose fan had adequate power to compensate for the nose-up pitching moment provided it was fitted with control scoops which deflected its exhaust upward through a large enough angle to provide the required nose-down control moment. In the actual case, it was necessary to modify the control system to provide adequate nose-down pitch control.

JET-LIFT CONFIGURATION

Only one jet-lift V/STOL transport configuration has been covered in free-flight tests - the Dornier DO-31 configuration shown in figure 19. This configuration is powered by two vectored thrust engines (each with four rotating exhaust nozzles) mounted in nacelles under the wing and by six lift engines mounted vertically, three to a pod, in the wing-tip pods. Pitch and yaw control was provided by jet reaction controls at the rear of the fuselage, and roll control was provided by differential throttling of the engines in the wing-tip pods. Related information on the dynamic stability and control of jet V/STOL aircraft has also been obtained in tests of four horizontal-attitude jet

V/STOL fighter models. These transport and fighter models have shown many common characteristics; so, even though direct experience with transport configurations has been limited, certain generalizations as to the dynamic stability and control of jet-lift V/STOL transports can be made.

The most important generalization that can be made is that in none of the flying model investigations made to date have any dynamic stability problems been discovered except those which result directly from static stability and trim characteristics that can be evaluated adequately from conventional static wind-tunnel tests. There are stability and control problems such as (1) static longitudinal instability (or pitch up), (2) static directional instability with inlets ahead of the center of gravity, (3) large nose-up pitching moments caused by jet interference which must be trimmed out with the controls, (4) large jet-induced lift losses such as those described in reference 22, and (5) wing stalling as a result of jet-induced local flow conditions or simply by excessive angle of attack; and all of these static stability and trim effects manifest themselves as dynamic motions of the model, but all of them could be recognized and their seriousness evaluated from conventional wind-tunnel tests on the basis of conventional airplane experience and a few calculations. For this reason it does not seem to be desirable to do any further free-flight model testing on jet V/STOL aircraft - except possibly as cheap insurance in support of a specific airplane development program.

The DO-31 model was no exception to the foregoing generalities. The model was flown in hovering, both level and descending transition conditions, and vertical take-offs and landings. It was found that, given adequate control power in accordance with existing requirements such as reference 12, the model could be flown easily in the hovering and transition ranges of flight without artificial stabilization. This is not to say that it can be expected that the full-scale airplane could be flown on instruments for all-weather approaches without artificial stabilization, but rather that it should be possible to fly the airplane satisfactorily under visual conditions without stability augmentation.

Short take-offs and landings were also made with this model with no evidence of any dynamic problems. These tests were made on the control-line facility described in reference 2 which permits the model the three longitudinal degrees of freedom, but restrains it in the three lateral degrees of freedom. If there were any dynamic problems peculiar to STOL operation it would be expected that they would be in the form of abrupt pitching motions or losses of height or excessive landing flare, but no such behavior was evident for the model.

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CONCLUSION

The foregoing discussion has shown that propeller- and lift-fan-powered V/STOL transport types have certain dynamic stability problems (mainly unstable stick-fixed oscillations) in hovering and low-speed flight, but that these instabilities can be controlled by the pilot without the use of artificial stabilization - although artificial stabilization is quite helpful. As the airspeed approaches that required for normal wing-borne flight, these instabilities are markedly reduced and usually disappear. In the approach condition for the tilt-wing type, that is, in descending flight in the transition speed range, very poor dynamic behavior can result from the tendency of the wing to stall if the aircraft is not properly designed to avoid this difficulty; and this poor behavior limits the descent angles that the pilot is willing to use. The jet V/STOL types have been found to have no real dynamic stability problems other than those associated with static stability and trim characteristics such as pitch-up, directional instability, and excessive pitch trim requirements which can be determined by ordinary wind-tunnel tests and interpreted adequately without the need for special dynamic tests.

Author

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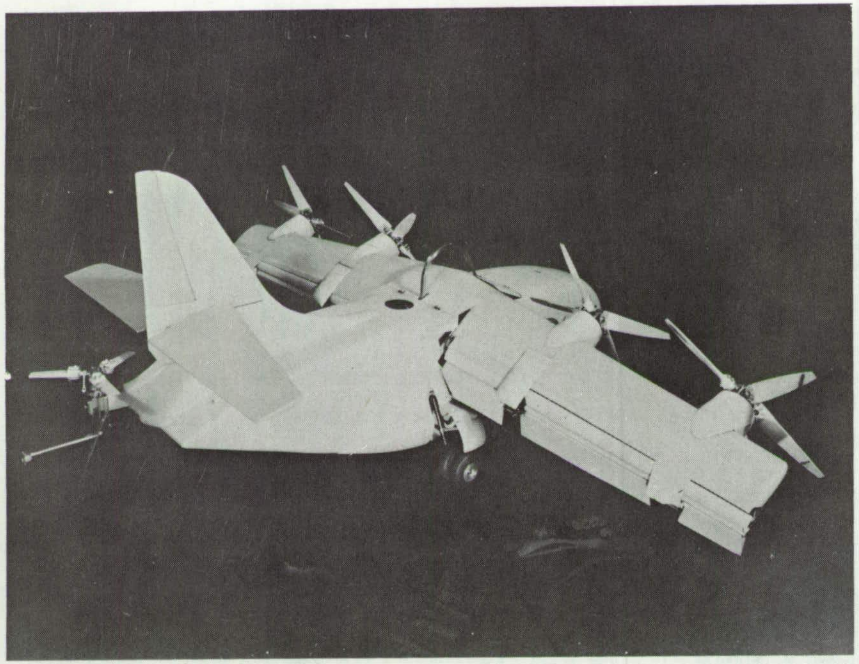


Figure 1.- Photograph of the 1/9-scale XC-142A flying model.

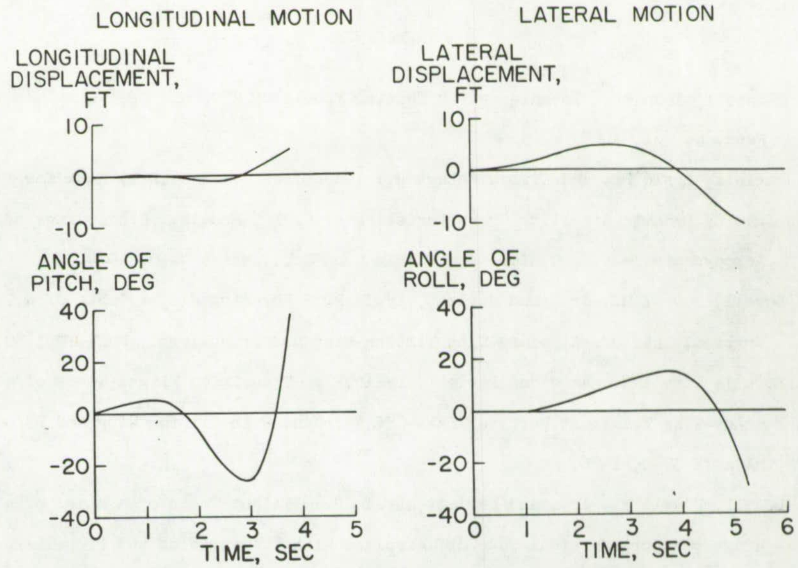


Figure 2.- Time histories of the stick-fixed pitching and rolling motions of the XC-142A model in hovering flight.

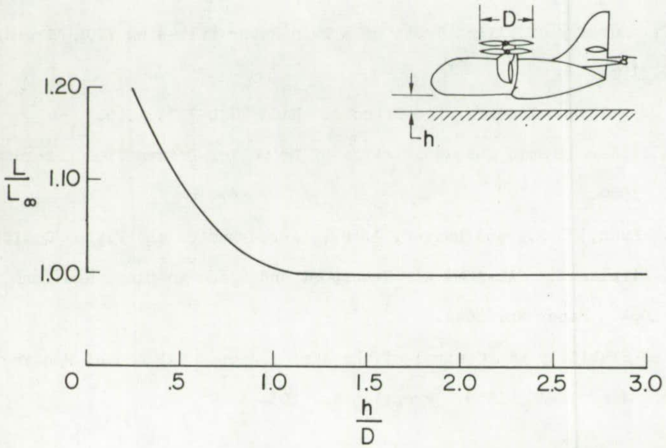


Figure 3.- Effect of ground proximity on lift of the XC-142A model.

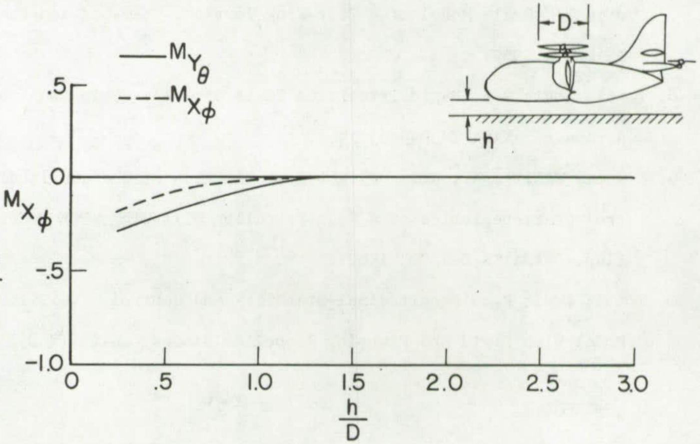


Figure 4.- Effect of ground proximity on static stability of the XC-142A model in hovering flight.

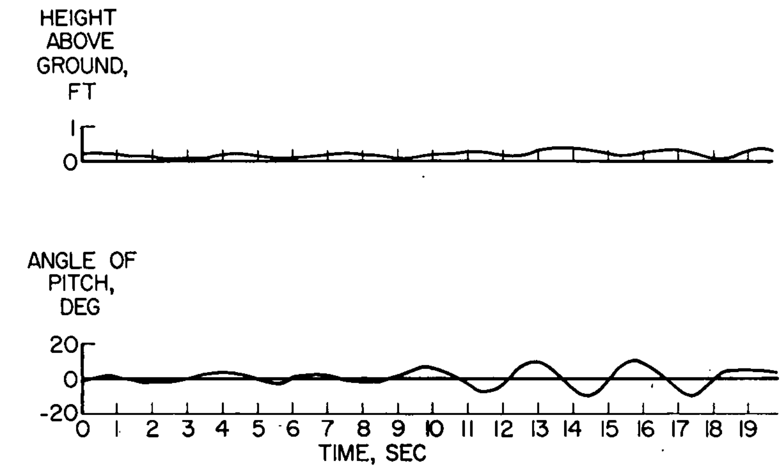


Figure 5.- Time history of stick-fixed pitching motion of the XC-142A model in ground effect.

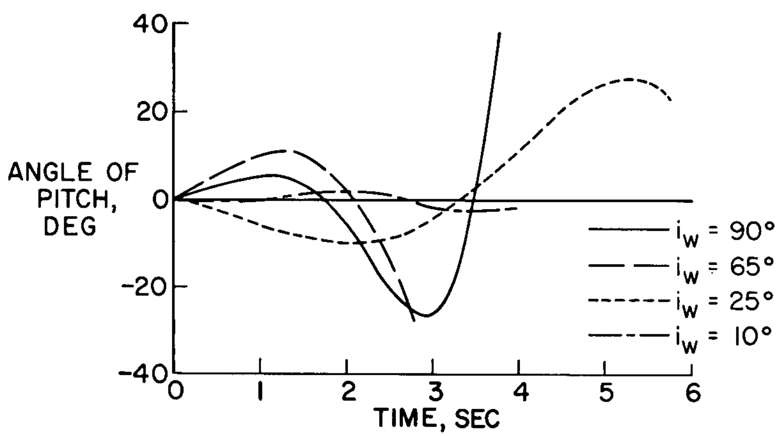


Figure 7.- Stick-fixed pitching motions of the XC-142A model in the transition flight range.

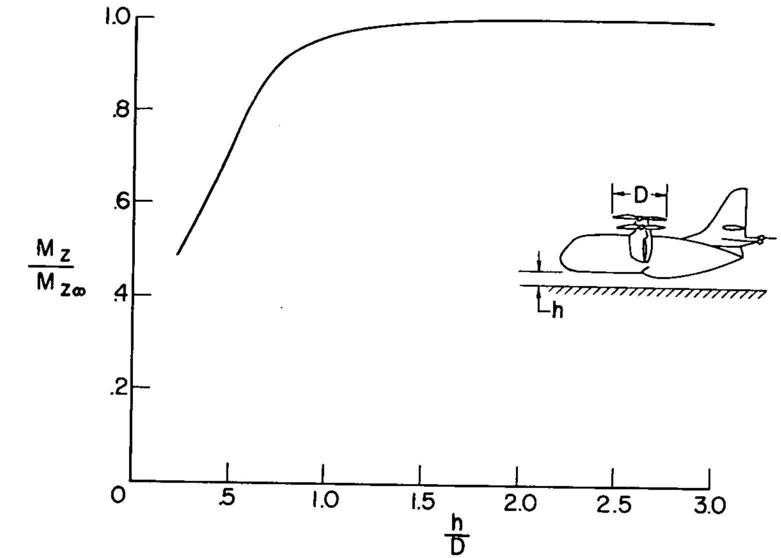


Figure 6.- Effect of ground proximity on the aileron effectiveness of the XC-142A model. $\delta_a = \pm 40^\circ$.

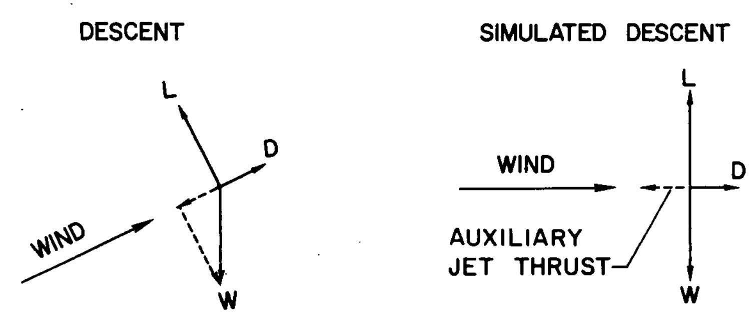


Figure 8.- Balance of forces in descent and simulated descent conditions.

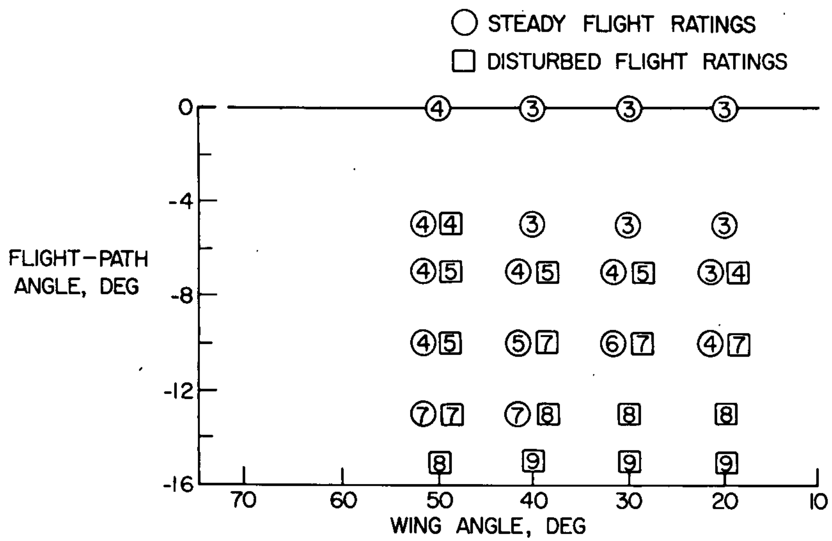


Figure 9.- Pilot ratings obtained in descent tests of the XC-142A model.

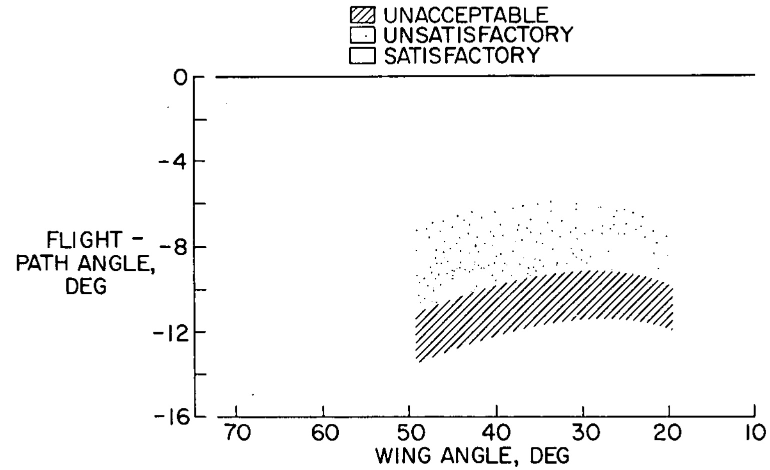


Figure 10.- Descent capability of the XC-142A model in the transition flight range.

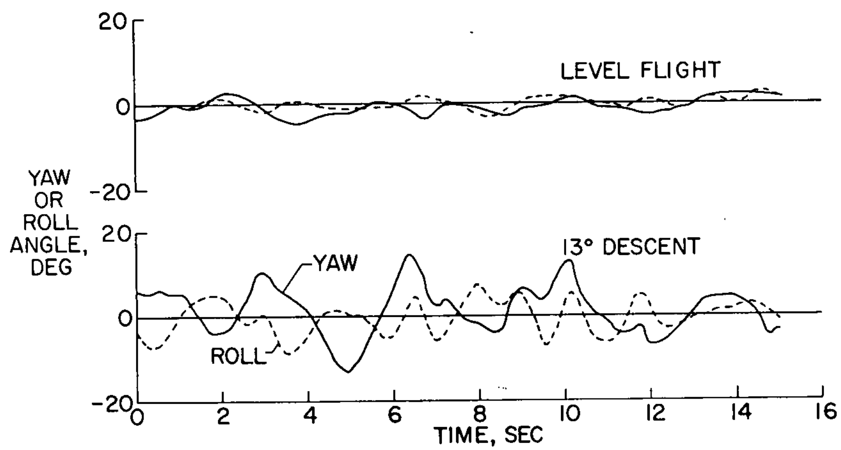


Figure 11.- Time histories of the XC-142A model in controlled flight without intentional disturbances. $i_w = 30^{\circ}$.

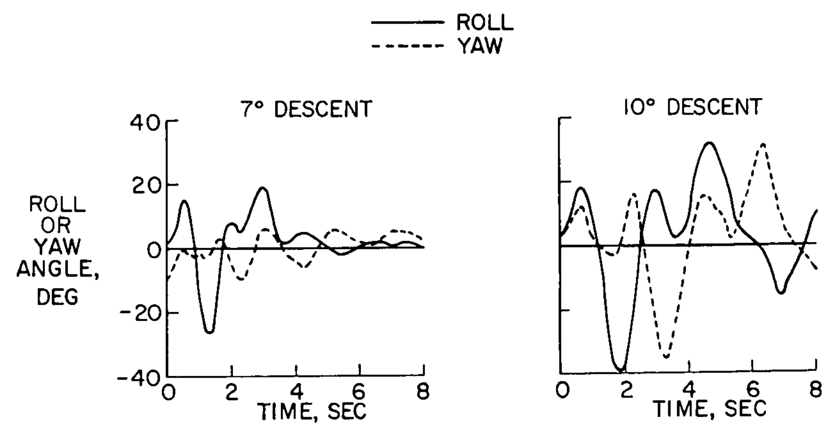


Figure 12.- Time histories of the XC-142A model in controlled flight after a deliberate disturbance. $i_w = 30^{\circ}$.

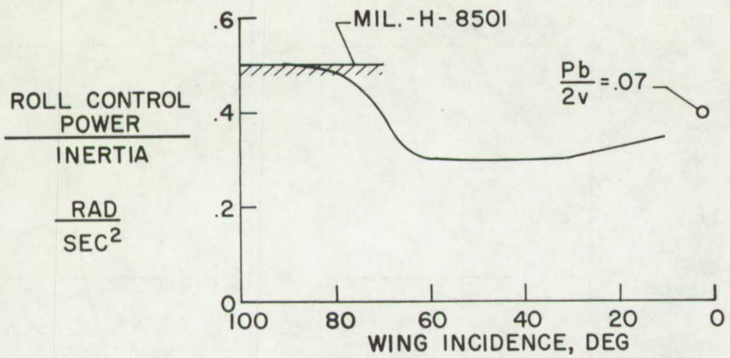


Figure 13.- Roll control power required on the XC-142A model in transition. Data scaled to full scale.

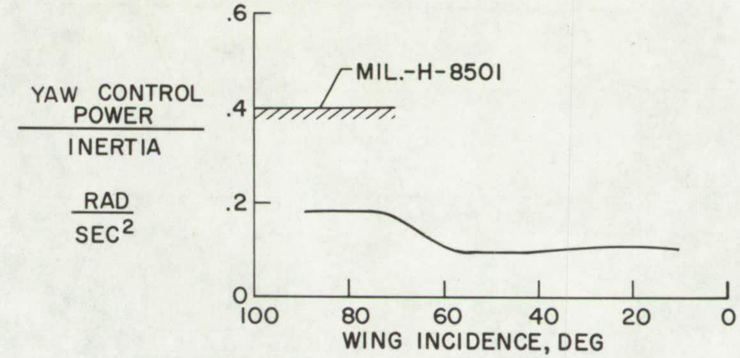
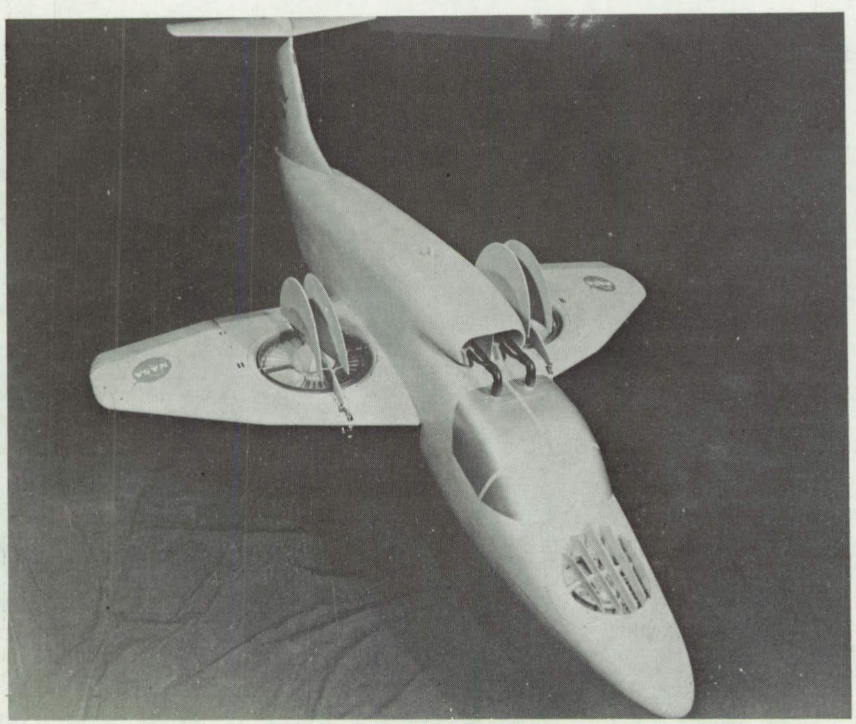
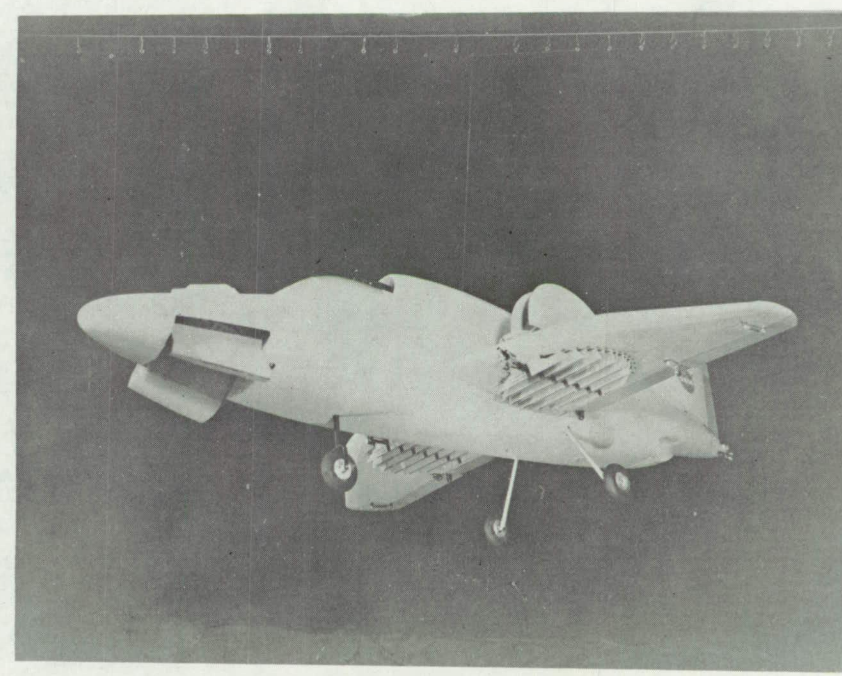


Figure 14.- Yaw control power required on the XC-142A model in transition. Data scaled to full scale.



(a) View of model showing fan inlets.

Figure 15.- Photograph of the 0.18 scale XV-5A flying model.



(b) View of model showing fan exit vanes.

Figure 15.- Concluded.

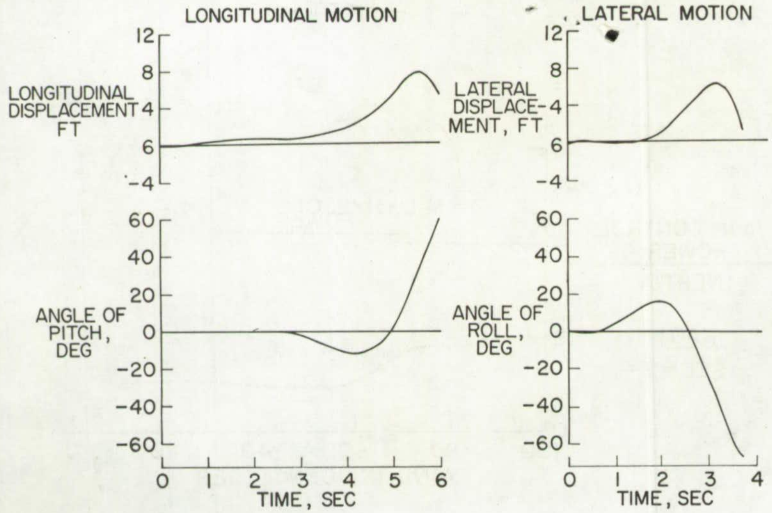


Figure 16.- Time histories of the stick-fixed pitching and rolling motions of the XV-5A model in hovering flight.

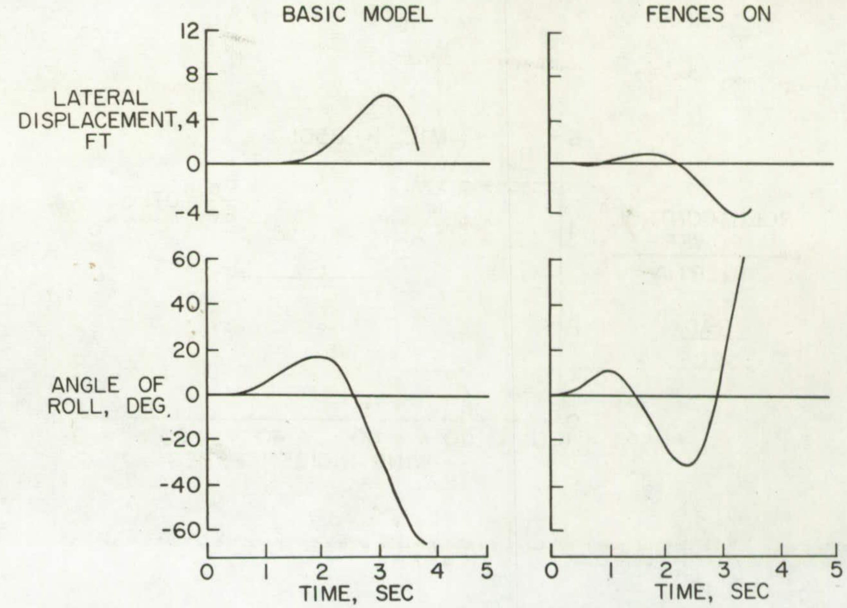


Figure 17.- Effect of fences on the stick-fixed rolling motion of the XV-5A model in hovering flight.

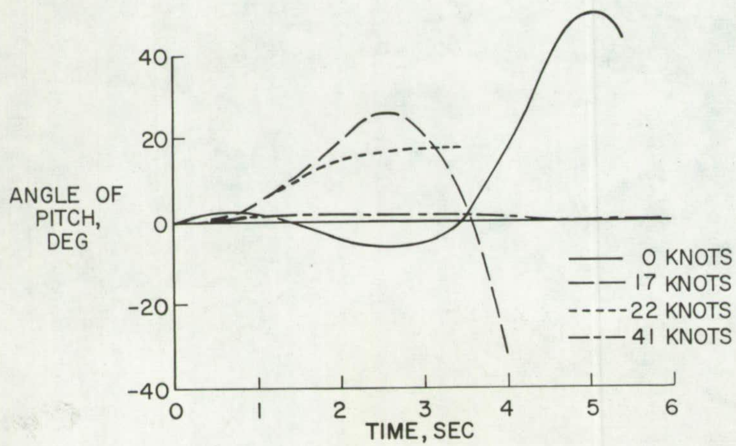


Figure 18.- Stick-fixed pitching motions of the XV-5A model in the transition flight range.

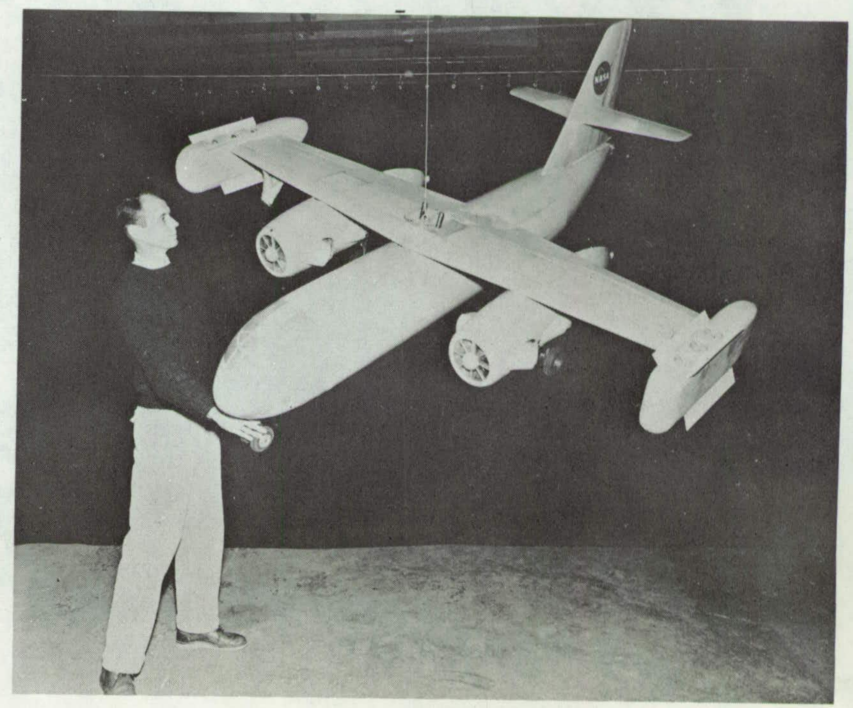


Figure 19.- Photograph of the 0.13-scale Dornier DO-31 flying model.